ANALYSIS OF ACCURACY AND MEASUREMENTS OF FLOWING MEDIUM PARAMETERS BY MEANS OF A WAVE THERMOANEMOMETER SYSTEM

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Summary: The paper analyses the measurement accuracy of selected parameters, such as flow velocity and temperature, of a flowing medium, by means of the thermoanemometric method. The core of the method relies on the Wave Thermoanemometer System constructed by one of the authors [1]. The sources of boundary error components are analysed within the signal conversion channels of the WTS. Errors are examined by means of relevant mathematical expressions representing signal conversion both in the velocity measuring channel and in temperature measuring channel. The algorithms have been developed for perfect and for real conditions. The theoretical considerations have been verified by laboratory tests performed by computerized equipment.

1. INTRODUCTION

The phenomena of gas and liquid flow are ubiquitous in our lives, both in ordinary activities as well as in industry [1], examples being examination and forecasting of weather, sewage disposal, controlling the emission of exhaust gas to the atmosphere, air pollution testing, food industry, medicine, etc. [3,4]. The widespread character of flow phenomena and their impact on technological processes stimulate research on new methods and devices for examining flow parameters. The most important flow parameters to be measured are flow velocity and temperature. As has been mentioned, there exist diverse applications of flow measurements. This has led to a significant diversity of measuring methods, differing with respect to principles of operation, complexity, accuracy etc. One of the methods relies on wave thermoanemometers, which measure the time needed for a heat marker wave to cover a known a priori distance Δl (Fig.1) between detectors situated in a measuring convertor immersed in the flowing medium (gas), carying a generated heat marker wave.

$$W_G = \frac{\Delta l}{\Delta t} \left[\frac{m}{s} \right] \qquad (1)$$

As is evident in the presented principle of WTS, the information on gas flow velocity is included in a wave of thermal pulses, floating in the medium under examination.

2. MEASUREMENTS BY MEANS OF THE WTS

The main element of the Wave Thermoanemometer System is a thermoresistive sensor. It can have three constructional variants, shown in Fig.1, that is a one-channel, two-element variant, a one-chanel three-element variant, and a two-channel, four-element variant.

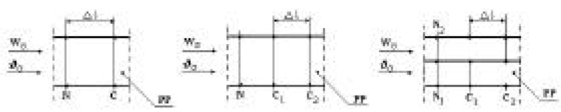

Fig.1 Constructional variants of the WTS thermoresistive sensor

The measuring method requires the sensor to be maximally compact, not to interfere with the flow field, and to be characterized by low inertion. Taking the above into consideration, the value of parameter Δl becomes quite important. From the perspective of measurement accuracy, the value of Δl should be sufficiently large. Practically, the values ranging from a few milimeters to a few meters can be encountered. Considering, however, all the other requirements, which are often contradictory, the value of Δl is typically closer to a few milimeters.

The three variants of the thermoresistive sensor discussed above are bases of three different measuring systems of the WTS [1,2]. Temperature measurement does not depend on the sensor variant, since only one its element is involved here as a resistive temperature sensor.

The version of the thermoresistive sensor presented in Fig.1b is the basis of the systemic variant of the WTS shown in Fig.2.

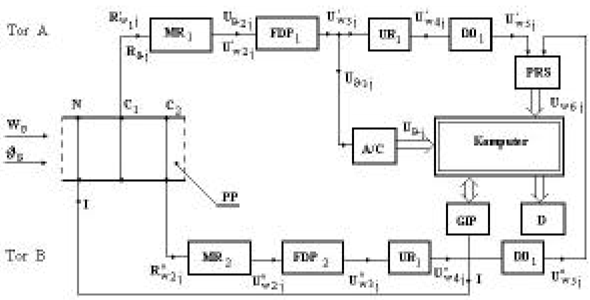

Fig. 2 WTS with a one-channel, three-element sensor

The measurement of flow velocity involves all the WTS subsystems except for the a/d converter. The thermoresistive parts of the sensor are influenced by the parameters of the flowing medium, i.e. by its flow velocity W_G and temperature ϑ_G. The sensor, being a parametric converter, responds by a change in the resistance of its elements C_1 and C_2, which evoke voltage signals U_W and U_ϑ. at the przek¹tnej of measuring bridges MR_1 and MR_2. At the subsequent subsystems of the WTS impulses are formed in the rectangular shape, which are then transmitted to the computer for further processing and determining flow velocity. The waveform of impulses as a function of time is presented in Fig.3.

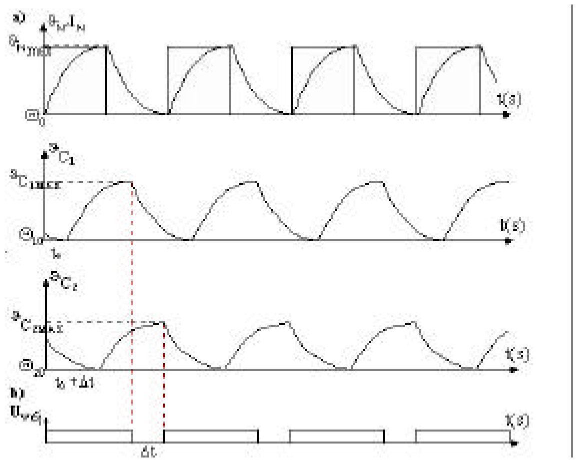

Fig. 3 Impulse waveforms in the one-channel, three-element sensor

The configuration of the system is quite complex. However, the system is free from measuring errors owing to dylatacji termicznej elementów C_1 i C_2.

3. MEASURING EQUATIONS AND METROLOGICAL PROPERTIES OF THE WTS

The analysis of metrological properties of the WTS was performed on the example of the one-channel variant with three thermoresistive elements N, C_1 and C_2. The channel of gas velocity flow W_G measurement consists of two mutually dependent paths. A change in the signal within these paths, from the entrance sensors C_1 C_2 being active elements of Wheatstone bridges, to the exit from the system, has the following functional form:

$$\left.\begin{matrix} I\ -\ W_{Gj} \rightarrow R'_{W1j} \rightarrow U'_{W1j} \rightarrow U'_{W2j} \rightarrow U'_{W3j} \rightarrow U'_{W4j} \rightarrow U'_{W5j} \\ II\ -W_{Gj} \rightarrow R''_{W2j} \rightarrow U''_{W1j} \rightarrow U''_{W2j} \rightarrow U''_{W3j} \rightarrow U''_{W4j} \rightarrow U''_{W5j} \end{matrix}\right\} \rightarrow$$

$$U_{W6j} \rightarrow \left[Z \left[U_{W6j} \right]_{\Delta_k t_W}^{h_p} \left[m_{WG} \right]_{\Delta_k m} \right]_{\Delta_k W_G}^{h_p} \qquad (2)$$

At the exits of the other subsystems the subsequent measuring equations were formulated in a similar fashion [1], which were then used for the transformations of Eqn.2.

The resulting equation, describing gas flow velocity is

$$W_{Gj}^{*}(t)=\left[\left[\Delta t_{W6j}\right]_{\Delta_k t_{WZ}}^{-1}\cdot\left[\frac{\Delta_k t_{Wt}\cdot U_{W6m}\cdot n\cdot\Delta l}{t_1}\right]_{\Delta_k m}\right]_{\Delta_k W_g}^{h_p} \qquad (3)$$

in which k = n = 5 "packages" of impulses.

As a result of the above mentioned mathematical transformations, an expression was obtained which is a mathematical model of the flow velocity measurement channel:

$$W_{Gj}^{*}(t)=\left[\frac{\Delta_k t_{WZ}\cdot U_{W6m}\cdot n\cdot\Delta l}{t_l\left[Z\left[U_{W6m}\sum_{k=1}^{n}\left[1\left(t-t_k^{'n}\right)-1\left(t-t^{'n}{}_k-\Delta t^{n}\right)\right]\right]_{\Delta_k t}\right]}\right]_{\Delta_k W_G}^{h_p} \qquad (4)$$

On the basis of the block diagram of the WTS (Fig.2) the necessary dependence was formulated capturing error structure in the examined flow velocity measurement channel:

$$\Delta W_{Gj}^{*}=W_{Gj}^{*}-W_{Gj}=\Delta_{\Delta l}W_{Gj}^{*}+\Delta_{f_{WZ}}W_{Gj}^{*}+\Delta_{m}W_{Gj}^{*}+\Delta_{\Delta t}W_{Gj}^{*}+\Delta_{l_i}W_{Gj}^{*}+\Delta_{n}W_{Gj}^{*} \qquad (5)$$

To define the components of the measuring error the following algorithms were formulated:

I – practical algorithm (actual)

$$W_{Gj}^{*}(t)=\left[\frac{\left[\frac{\Delta_k t_{WZ}\cdot U_{W6}m\cdot n\cdot\Delta l}{t_1}\right]_{\Delta_k m_W}}{Z\left[U_{W6}m\sum_{k=1}^{n}\left[1\left(t-t_k^{n}\right)-1\left(t-t_k^{n}-\Delta t^{n}\right)\right]\right]_{\Delta_k t}}\right]_{\Delta_k W_G}^{h_p} \qquad (6)$$

II – perfect algorithm (hypothethical)

$$W_{Gj}(t)=\left[\frac{\left[\frac{\Delta_k t_{WZ}\cdot U_{W6}m\cdot n\cdot\Delta l}{t_1}\right]_0}{Z\left[U_{W6}m\sum_{k=1}^{n}\left[1\left(t-t_k\right)-1\left(t-t_k-\Delta t\right)\right]\right]_0}\right]_0 \qquad (7)$$

where $t_k = t_0 + t_i + T(k-1)$: $t_i = 1, 2, ..., n$; k = 5

Using the above algorithms, one can specify measuring equations for all the error components occurring in the velocity flow and temperature measurement channel. The algorithms, the equations, together with a PC equipped with specialized software MICRO – CAP II provided a basis for extensive simulations and empirical testing at a test stand. The results obtained suggest that from among the six error components only three influence significantly the results of measurements by means of the WTS, the three significant componenets being construction component $\Delta_{\Delta l}W^{*}_{Gj}$ (0,13%), flip-flop PRS component $\Delta_{\Delta t}W^{*}_{Gj,}$ (0,07%), and discretization component $\Delta_{m}W^{*}_{Gj}$ (0,3%).

For the sake of completeness and clarity the results obtained will be also presented graphically. To demonstrate that the distribution is correct, selected results [1]are ordered from the smallest value $W_{G\,min}$ to the greatest value $W_{G\,max}$, thereby forming a distributive series (Table 1). The area included between $W_{G\,min}$ and $W_{G\,max}$, called range R, from a sample of population n (5 measuring series, 10 observations each), was divided into **r** intervals closed from the right side, of width **h ,** called zones.

For analysis of the first group of measurement results (Table 1) the number of zones was assumed as r = 7, accordingly with [1, 4]. Zone width **h** was assumed constant for the whole range **R** and calculated as follows

$$h=\frac{R}{r}=\frac{W_{G\,max}-W_{G\,min}}{r} \qquad (8)$$

obtaining h = 0,0063 m/s for the results in Table 1.

On the basis of Table 1, the results of measurements can be presented graphically in the form of corresponding histograms and frequency polygons (Fig.4)

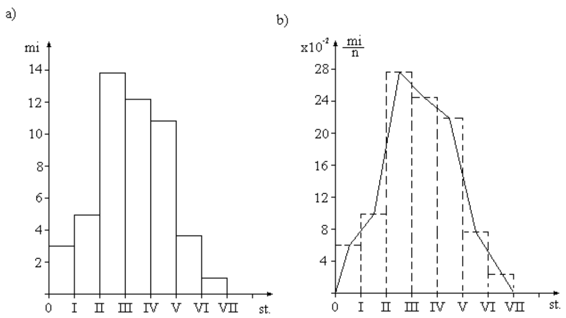

Fig. 4. Measurement results from a series, obtained by means of the WTS a) histogram, b) frequency polygon

Thus, the measurement results represented graphically in the form of a histogram and frequency polygon (Fig. 3 a and b, respectively) indicate that the distribution of individual results in each series is normal. Considering the fact that the WTC collaborates with a computer, which ensures obtaining extensive measuring series within short periods of time, the results so obtained should be processed by means of the Gauss normal distribution.

Table 1: Auxiliary data for the analysis of WTS measurements [1] in the form of a graphic representation.

Zone number	Zone intervals	Zone contents		Frequency	Zone centre	$W_{gœ} m_i$	$W_{Gœ} - W_{Gj}$	$(W_{Gœ} - W_{gj})^2$	$(W_{Gœ} - W_{gj})^2 m_i$
		graphic	numeral m_i	m_i / n	$W_{Gœ}$				
0	- ∞								
1	0,737 - 0,7433	III	3	0,06	0,7401	2,220	- 0,017	0,0003	0,0009
2	0,7433 - 0,7496	IIII II	5	0,1	0,7464	3,732	- 0,011	0,0001	0,0005
3	0,7496 - 0,7559	IIII IIII IIII II	14	0,28	0,7527	10,538	- 0,005	0,000025	0,0003
4	0,7559 - 0,7622	IIII IIII IIII	12	0,24	0,759	9,108	- 0,001	0,000001	0,00001
5	0,7622 - 0,7685	IIII IIII III	11	0,22	0,7653	8,418	- 0,008	0,000064	0,0007
6	0,7685 - 0,7748	IIII	4	0,08	0,7716	3,086	0,014	0,0002	0,0008
7	0,7748 - 0,7811	I	1	0,02	0,7779	0,778	0,020	0,0004	0,0004
8	+ ∞								
Σ	→	→	n=50	1,00	→	37,880	→	→	0,00361

4. CONCLUSIONS

- Establishing time as an absolute value in a wave anemometer constitutes an important development in thermoanemometry.
- The use of computer for processing the measuring data in the process of gas parameter measurement ensures full automation and fast analysis of boundary error components.
- The fact that the operation of the WTS is time-based makes it possible to neglect several factors, such as the influence of sediments on the thermoresitive sensor, the question whether the flow is isothermal, tensometric effect, and so on.

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